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The borderlands of waking: Quantifying the transition from reflective thought to hallucination in sleep onset

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Abstract

We lose waking consciousness spontaneously and regularly over the circadian cycle. It seems that every time we fall asleep, reflective thinking gradually gives way to our interactions with an imaginary, hallucinatory world that brings multimodal experiences in the absence of adequate external stimuli. The present study investigates this transition, proposing a new measure of hallucinatory states. Reflective thinking and motor imagery were quantified in 150 mentation reports provided by 16 participants after forced awakenings from different physiology-monitored time intervals after sleep onset. Cognitive agency analysis and motor agency analysis – which are objective (grammatical–semantic) tools derived from linguistic theories – show (i) a decrease in reflective thinking which sleepers would need to acknowledge the hallucinatory quality of their state, and (ii) an increase in motor imagery, indicating interactions with a hallucinatory world. By mapping these spontaneous changes in human consciousness onto physiology, we can in the long run explore the conditions of its decline, and possibilities for treatment.

Keywords

Consciousness; Dreaming; Motor imagery; Linguistics; Mentation reports; Hypnagogic hallucinations; Schizophrenia

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Introduction

The transition from quiet waking to sleeping involves a variety of physiological changes. These changes involve chemical neuromodulation based on the interaction of aminergic and cholinergic systems, resulting in the hypoactivation of frontal regions, including the dorsolateral prefrontal and orbitofrontal cortex (Fosse et al., 2001 and Hobson et al., 2000). Cerebral areas are known to fall asleep at different times. It has for example been shown that the left hemisphere has a shorter sleep onset latency than the right (Casagrande and Bertini, 2008, Casagrande et al., 1996 and

Casagrande et al., 1995). On the level of behaviour, we can see a decrease in performance over the course of time with regard to reacting to external stimuli or carrying out repetitive motor tasks, such as finger tapping (Casagrande et al., 1997, Casagrande et al., 1996 and Violani et al., 1998).

This study investigates the accompanying psychological and cognitive changes, specifically the transition from reflective thinking towards hallucination: earlier studies suggest that “normal, wake-like thoughts” decrease from waking to sleep onset, to non-REM, and finally REM sleep (Fosse et al., 2001 and Speth and Speth, 2016), to be replaced by “unusual thoughts” and hallucinations as multimodal perceptions occurring in the absence of adequate external stimuli (Rowley et al., 1998 and Silbersweig et al., 1995). To complement previous content-based ratings, the present study proposes a new, quantitative measure of hallucinatory states: mentation reports from sleep onset, the physiological markers of which were determined by the nightcap sleep monitoring device (Ajilore et al., 1995, Cantero et al., 2002 and Stickgold et al., 2001), are linguistically quantified via cognitive agency analysis and motor agency analysis.

We hypothesize that mentation reports collected from later in sleep onset will exhibit a decline in reflective thinking. We further hypothesize that motor imagery, as a positive symptom of hallucinations, will increase over the course of sleep onset: motor imagery can be seen as an indicator of interactions with an imaginative, or hallucinatory, world, or of the (mental) navigation through this world. It has previously been shown that motor imagery differs systematically across sleep states – whereby REM sleep shows highest levels of motor imagery, followed by non-REM sleep, while sleep onset exhibits the lowest levels of motor imagery (Speth et al., 2013 and Speth and Speth, 2016). The present analysis should thus reflect an increase in motor imagery as participants transition from sleep onset to non-REM sleep. Mentation reports collected from later as opposed to earlier in sleep onset should contain more references to motor imagery. We will further (a) learn if quantitative linguistic analysis is a feasible tool to investigate mentation during a transitional state of consciousness, and (b) observe the shape of the function of the decline in cognitive agency versus the ascent of motor agency.

The results could pave the way for an improved understanding of the mechanisms of the human capacity for reflective thinking, and the physiological conditions of its decline: the present tool can allow for greater qualitative and quantitative accuracy in mapping the psychological markers of hallucinatory states onto physiological changes – as opposed to merely dichotomous ratings of individuals’ mentation during specific states of consciousness as “lucid” versus “hallucinatory” by third person raters. The present measure further brings higher objectivity, reliability, and validity in comparison to investigations that rely solely on the (probably differing) self-evaluations of participants who may exhibit individual interpretations of the abstract, latent variables that are to be tested here (see Speth et al., 2013 and Speth et al., 2015 on the greater qualitative and quantitative accuracy of linguistic tools in quantitative mentation report analysis, and Windt, 2013 as well as Speth, Harley, & Speth, in press, on the crucial distinction between third person ratings of mentation reports versus participants’ opinions of their own mental events as obtained via questionnaires). The present measure can potentially be used to reveal the distinct patterns of connected changes in (i) reflective thinking, and (ii) motor imagery, as functions of (iii) physiological changes such as described above.

An improved knowledge of the changes in mentation that occur en route to hallucinatory states could in the long run be beneficial for improved clinical diagnoses and therapy. First, prominent changes in mentation could draw our attention to the connection between distinct physiological changes and specific markers of human mentation, as well as their pathological alterations. An understanding of the distinct interplay of (pathological) physiological changes and human mentation may bring progress in two groups of therapeutic treatment: It may allow (i) for better pharmacological treatment or refined protocols for electrical brain stimulation to target changes in physiology. It may also allow for (ii) improved treatment plans in cognitive-behavioural therapy that target changes in mentation. A third area of application may be (iii) the combination of treatments targeting changes in physiology as well as changes in mentation, for example in the context of the increasingly popular bio- or neurofeedback systems where acoustic or visual signals of changes in physiology can be used as positive or negative reinforcements of users' mental strategies. Especially spontaneous motor imagery has been shown to lend itself to such manipulation (Speth et al., 2015), and the current measure for hallucinatory states may in the future reveal new opportunities for treatment.

Method

Linguistic analysis was conducted on a database of mentation reports from sleep onset. References to reflective thinking and motor imagery were rated blindly. Analysis was conducted with pre-validated tools derived from established grammatical and semantic theories.

Database

The database comprised 150 reports obtained from sixteen university students (8 male, 8 female). Participants were 19–26 years of age, had provided informed consent, and received financial compensation for participating in the study. Participants were required to complete a preliminary training protocol before asked to deliver oral mentation reports over a fourteen day period. The reports were conceived with a dictation device after instrumental awakenings by a noise signal. Awakenings were initiated by the Nightcap, a sleep-stage detection device that has been shown to reliably detect sleep onset based on changes in eyelid movement patterns (detailed information on the Nightcap database can be found in Stickgold et al., 2001). Reports could thus be collected from quiet waking, as well as 15, 45, 75, 120, or 300 s after sleep onset. The transcribed oral reports were edited according to the technique of Antrobus (1983), which involved removing participants' additional commentary on their mentation.

Linguistic analysis of motor imagery

Linguistic indications of motor imagery were quantified by means of motor agency analysis (Speth et al., 2013 and Speth et al., 2015), a grammatical tool based on linguistic theta theory (Gruber, 2001, Reinhart, 2002 and Reinhart and Siloni, 2005). References to motor imagery were quantified as grammatical (theta role) agencies that denote manner-of-motion verbs. The tool has been pre-validated by linking the number of linguistic references to motor imagery with patterns of motor cortical activation of REM sleep versus sleep onset hypnagogia, as well as under tDC stimulation. The tool has been shown to be reliable (Speth et al., 2013 and Speth et al., 2015).

In theta theory, the grammatical agent is a noun phrase that stands in a specific relationship to a verb phrase, performing the action described by the predicate. Note that the grammatical agent is often but not necessarily congruent with the syntactic subject. In motor agency analysis, only those agencies that describe (simulated) motor movement are counted.

Further, to account for the fact that the English language comprises many movement metaphors and idioms, the intensity of the motor imagery was determined by classifying motor agencies as athletic versus non-athletic according to the list of Olympic and World Games disciplines (compare http://www.olympic.org/sports, https://www.theworldgames.org/the-sports/sports). The phrase “Mimi walked to Rome” would thus be classified as denoting more intense motor imagery than the phrase “Mimi went to Rome”.

Linguistic analysis of cognitive agency

Linguistic indications of reflective thinking were quantified by means of cognitive agency analysis. Cognitive agency analysis is a tool that is likewise based on linguistic theta theory, but quantifies grammatical agencies related to the semantic field of cognitive acts (for detailed information, please see Speth and Speth, 2015a, Speth and Speth, 2015b and Speth and Speth, 2016, and Speth, Speth, et al., in press).

Statistical analyses

The numbers of motor agencies, athletic motor agencies, and cognitive agencies per report were compared across the different times after quiet waking and sleep onset by means of a one-way analysis of variance (ANOVA). Fishers’ least significant difference (LSD) testing was conducted post hoc. A Pearson product-moment correlation was used to assert an association between time after sleep onset and the number of motor agencies, athletic motor agencies, and cognitive agencies. To show the relation between the different kinds of agencies, the difference between motor agencies, athletic motor agencies, and cognitive agencies was calculated for each report. An ANOVA was conducted to test for changes in these difference values. To allow for better comparability with earlier findings, the percentages of reports containing one instance or more of motor agency, athletic motor agency, or cognitive agency are also reported for each interval. As the length of the mentation report is an important dependent variable in many dream studies, and is for example dependent on the time of night (Casagrande, Violani, Lucidi, Buttinelli, & Bertini, 1996) and/or the modality of reporting (Casagrande and Cortini, 2008 and Casagrande et al., 1996), the mean report length (word count) was also calculated. An analysis of covariance (ANCOVA) with word count as covariate was conducted for motor agency and cognitive agency. Fisher’s LSD testing was used post hoc.

Results

Of the 150 reports, 35 were collected when the participant was still awake, and 27 reports were collected from 15 s, 20 from 45 s, 26 from 75 s, 18 from 120 s, and 24 from 300 s after sleep onset.

The mean number of words per report per time of awakening was as follows. Still awake: 56.9 (SD = 27.3); 15 s: 44.4 (SD = 20.8); 45 s: 44.1 (SD = 18.8); 75 s: 49.2 (SD = 22.4); 120 s: 36.3 (SD = 17), 300 s: 35.8 (SD = 18.3). This difference was statistically significant (F (5, 144) = 3.72, p = .003; $\eta 2$ = .114): Reports from waking tended to be longer than reports collected at 15 s (p = .026), 45 s (p = .037), 120 s (p = .001), and 300 s after sleep onset ($p > .001$), and reports collected 75 s after sleep onset were longer than reports collected 300 s after sleep onset (p = .031).

In total, 70.7% of all reports exhibited one instance or more of cognitive agency, 15.3% exhibited one instance or more of motor agency, and 4% exhibited one instance or more of athletic motor agency. Please see Table 1 for linguistic samples, and see Figure 1 for the changes in percentages over time.

Table 1: Linguistic samples from mentation reports from 15 s, 45 s, 75 s, 120 s, and 300 s, after sleep onset. The type of agency (cognitive agency, motor agency, athletic motor agency) and the grammatical perspective (first, second, third) from which the agency is reported are given.

	Linguistic sample	**Agency type (cognitive, motor, motor-athletic) and grammatical perspective**
15 s after sleep onset	I was thinking about E. V. who's a friend of mine from Exeter and I was thinking about how we were supposed to get drunk -- not get drunk but like have a drink together and talk about shit. And I was thinking about like the two of us back in high school and stuff, how we interacted and everything in like a rock band that was in. He used to play guitar and stuff. I was thinking about the rock band, The Atomic Chia Pets.	4 x first person cognitive agency
	I was just thinking about laundry and putting two colors together that don't go together and the ironing, And something to do with the poetry room too, about ironing something for that.	1 x first person cognitive agency
45 s after sleep onset	I cannot believe the number of times that I have to wake up and do tape. And I was sort of having that thought and having that thought evolve	2 x first person cognitive agency
	In my mind I was bouncing this rubber ball that a friend of mine gave me so actually I can feel it and I guess I thought I sort of was bouncing it	2 x first person motor agency, athletic
75 s after sleep onset	I think I was sort of baking up a grand plan in my head for how I was going to get in shape for the next couple days; been trying to do this running regimen between three and four. But it hasn't been working too well because of the Meso paper and stuff. And I was just thinking how I really want get in shape for the Senior Soiree and things like that.	2 x first person cognitive agency
120 s after sleep onset	I was thinking about the rules of naming and where all the names come from and right before that I was straightening my Nightcap, making sure everything is all where it's supposed to be. And I just want to go to sleep and I was wondering when this onset part ends. I was thinking it takes an hour. Then it keeps waking you up	3 x first person cognitive agency
	Playing tennis. And it was sunny and warm and we were in Florida `cause I think we were … golf course; courses and my Dad was there	1 x first person motor agency, athletic

300 s after sleep onset	I was half dreaming and half thinking about just hanging out with a bunch of people and we were just sitting around talking. I think I was talking about different places I'd visited. I was thinking about different like places to hang out with friends	2 x first person cognitive agency
	I'm in my house in Delaware and there's people starting to come in. It's a party and it's getting crowded, we're getting dressed up for the formal but the guys weren't wearing tuxedos.	1 x third person plural motor agency 1 x first person plural motor agency
	I was wandering on some kind of hill that was near a port and two minutes or so before I saw like a white light. It was weird; but no light this time. Grocery shopping I think was in there too from this time	1 x first person singular motor agency

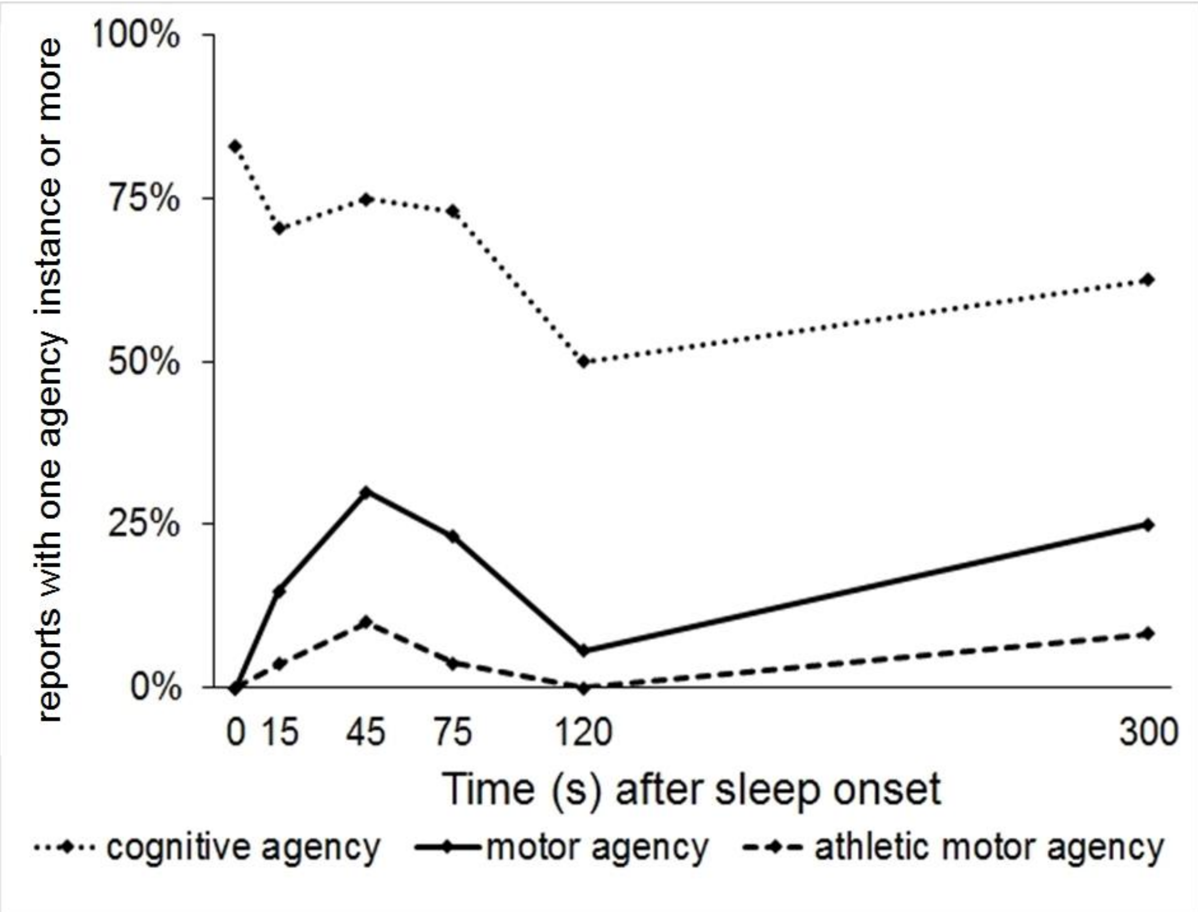

Figure 1: Percentages of reports with one instance or more of cognitive agency, motor agency, or athletic motor agency before sleep onset, and conceived 15, 45, 75, 120, and 300 s after sleep onset. Note that athletic motor agency is a subcategory of motor agency.

The number of cognitive agencies (F (5, 144) = 3.14, p = .01; η2 = .098) and motor agencies (F (5, 144) = 2.9, p = .016, η2 = .092) differed over time. There were fewer instances of cognitive agency at 75 s (M = 1.1, SD = 1.01; p = .01), 120 s (M = 0.74, SD = 0.89; p = .001), and 300 s (M = 0.97, SD = 1.07; p = .004) after transition to sleep in comparison to when participants were still awake (M = 1.8, SD = 1.5). In contrast, there were more instances of motor agency at 45 s (M = 0.35, SD = 0.59; p = .007), 75 s (M = 0.31, SD = 0.62; p = .01), and 300 s (M = 0.33, SD = 0.64; p = .006) after the transition to sleep in comparison to wakefulness (M = 0, SD = 0). The number of athletic motor agencies did not differ over time. See Figure 2.

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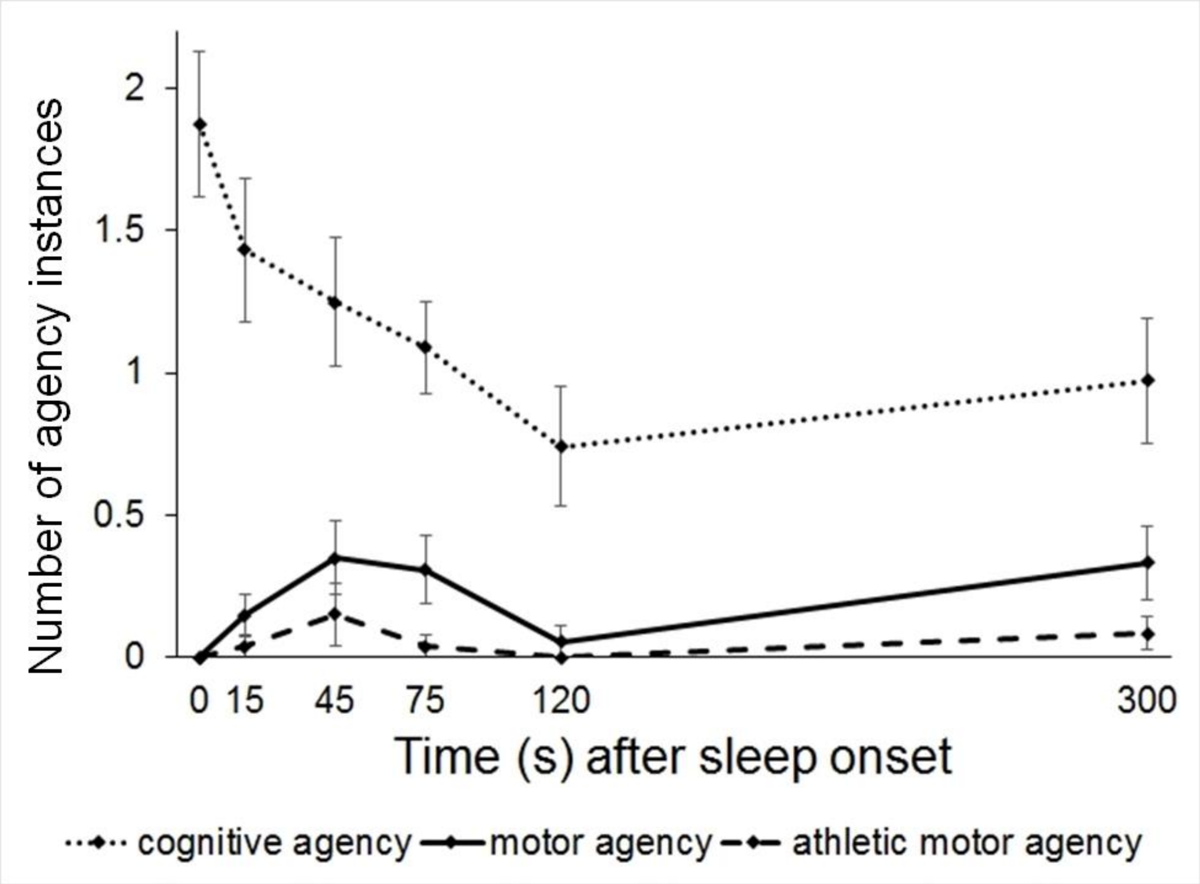

Figure 2: Mean number of instances of cognitive agency, motor agency, and athletic motor agency in reports from waking, and conceived 15, 45, 75, 120, and 300 s after sleep onset. Error bars indicate the standard error of the mean. Note that athletic motor agency is a subcategory of motor agency.

When the number of words per report was used as a covariate of cognitive agency, the effect of time on cognitive agency was not significant (F (5, 143) = 1.39, p = .23). Motor agency however, when corrected for report length, differed significantly over time (F (5, 143) = 2.953 p = .014, partial η2 = .094). There were fewer motor agencies in reports from quiet wake compared to reports collected at 45 s (p = .006), 75 s (p = .009), and 300 s after sleep onset (p = .006).

A Pearson product-moment correlation revealed a negative relationship between the time progressing after sleep onset and cognitive agency: the longer the time period after sleep onset, the fewer cognitive agencies were observed in the mentation reports. There was further a positive relationship between motor agency and athletic motor agency. See Table 2.

	1	2	3
1. time after sleep onset			
2. cognitive agency	-.21**		
3. motor agency	.16	-.01	
4. athletic motor agency	.06	-.02	.46**

** p < .01

Figure 3: Pearson correlation coefficients between (1) time after sleep onset, (2) cognitive agency, (3) motor agency, and (4) athletic motor agency.

In a second step of analysis, the differences between the number of cognitive agencies and motor agencies were calculated for each report. The difference between cognitive agency and motor agency decreased over time (F (5, 144) = 4.41, $p = .001$; $\eta 2 = .133$). See Figure 3.

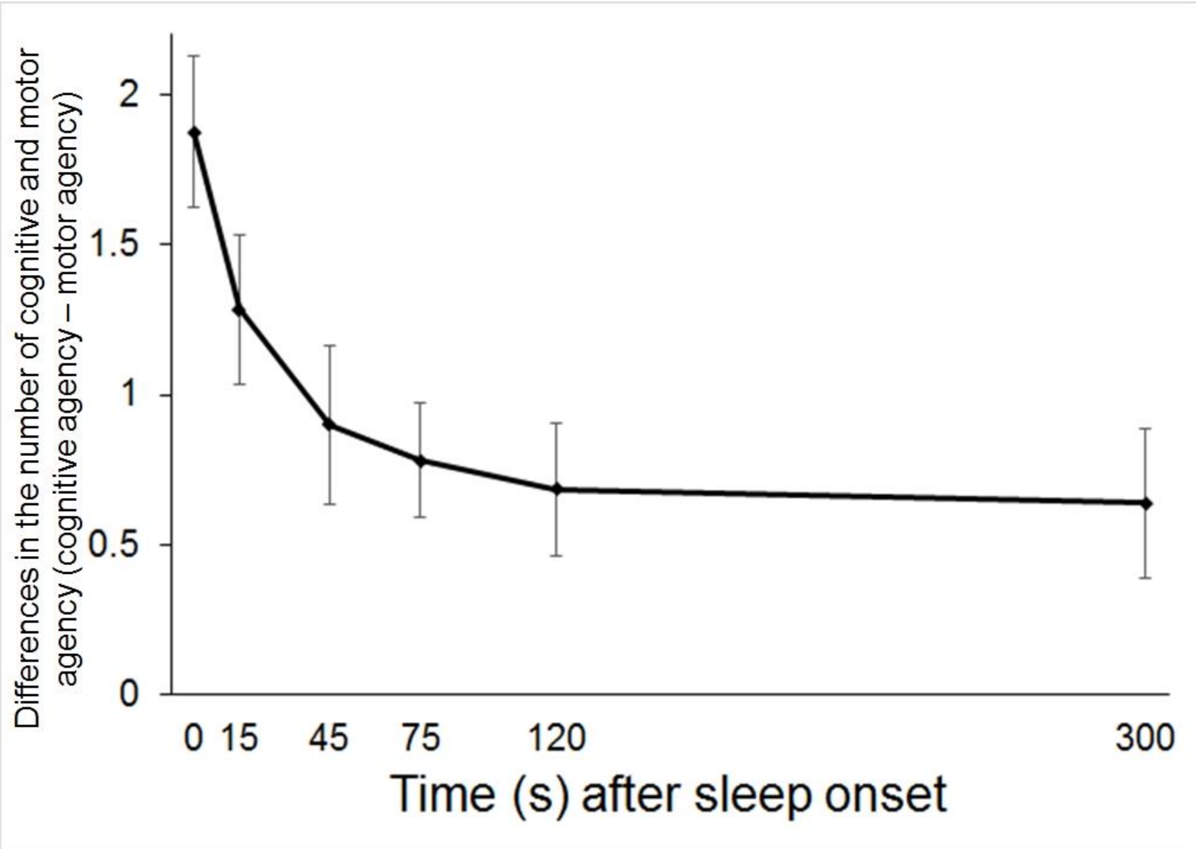

Figure 4: Difference in the number of cognitive and motor agencies per report from waking, and conceived 15, 45, 75, 120, and 300 s after sleep onset.

Discussion

This study set out to investigate the transition from reflective thinking to hallucinatory experiences, which is hypothesized to occur at sleep onset along with a series of physiological changes, including the hypoactivation of the dorsolateral and the orbitofrontal cortex (Fosse et al., 2001). Mentation reports from quiet waking as well as reports collected at 15, 45, 75, 120, or 300 s after sleep onset were analysed blindly by means of cognitive agency analysis and motor agency analysis – quantitative linguistic tools which could recently show that reflective thinking decreases across states of consciousness, from quiet waking to sleep onset, to non-REM, and finally REM sleep (Speth & Speth, 2016), and that sleep onset involves less motor imagery than REM sleep (Speth et al., 2013). The present results suggest that mentation reports collected from later in sleep onset exhibit a decline in references to reflective thinking, with the number of cognitive agencies reduced by half at circa 120 s after sleep onset, despite the fact that these reports cover a larger mentation span. At the same time, motor imagery as a positive symptom of hallucination (indicating the interaction with an imaginative world in the absence of adequate external stimuli) increases during sleep onset. In so far as (i) quantitative differences in linguistic cognitive agency and motor agency in the mentation reports refer to changes in reflective thinking and motor imagery, it seems that (ii) these are independent, meaningful factors that mark significant changes in cognition within the short period of sleep onset, wherein (iii) reflective thinking appears to decline rapidly and steadily, while motor imagery increases.

For motor agency, these results are robust to the correction for report length, while they are not so for cognitive agency. A reason for this could be that the correction for report length is not always adequate for the empirical analysis of mentation reports: as mentation content and mentation report length are not independent of each other, a correction for report length can lead to the exclusion of meaningful elements from our analysis (Hobson et al., 2000, Speth et al., in press and Speth and Speth, 2016).

The present study provides a first proof of principle that it is feasible to quantify the level of reflective thinking and motor imagery in mentation reports from different times of sleep onset to observe the transition towards a hallucinatory state. The tool in the present study could thus be used for future investigations of sleep onset: as a discrepancy between physiological indicators of sleep onset and the subjective feeling of falling asleep is known to occur in healthy participants (Casagrande et al., 1997) as well as in participants diagnosed with sleep disorders (Moon, Song, & Cho, 2015), a further study could show how this sensation corresponds not only with physiological variables, but also with levels of cognitive agency and motor agency in mentation reports. Future investigations could also combine motor tasks (such as finger tapping by which participants signal that they are still awake; see Casagrande et al., 1997), physiological measurements, and motor agency analysis, for a closer investigation of the relations between physiology, behaviour, and subjective experience in sleep onset.

These insights could in the long run help us to better understand and treat the physiological and psychological causes around a loss of reflective thinking as it occurs in connection with acute hallucinatory episodes in different psychopathologies such as schizophrenia, post-traumatic stress disorder, and dementia: an improved knowledge of the changes in mentation en route to hallucinatory states could in the long run thus help both basic science and applied clinical research.

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